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Assessment of offshore shrimp stocks of Bangladesh based on commercial shrimp trawl logbook data

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ABSTRACT

This study presents the results of analytical assessment of offshore shrimp stock in Bangladesh marine waters. A time series of annual catch per unit effort (CPUE) was derived from commercial logbook data during the period from 1986 to 2016 and used as a turning series for a Schaefer biomass model. The current stock size and annual harvest rate were estimated to be around 20300 t and 20% respectively, with the stock size increasing in the last ten years. The estimated maximum sustainable yield (MSY) reference points with 95% confidence intervals are optimal biomass B_{MSY} = 15800 t (11300-22000 t) and optimal harvest rate u_{MSY} = 30% (21-42%). The average annual catch was 4650 t, close to the estimated MSY of 4710 t (4570-4860 t). Overall, the stock is estimated to be in a good state and the data show that CPUE in recent years is slightly above the long-term average. The assessment results are subject to considerable uncertainty, reflected in wide confidence intervals around the estimated stock status. Moreover, the simple assessment model has restrictive assumptions that may not capture the underlying dynamics of the Bangladesh shrimp fishery, a multispecies tropical fishery with changes in the fleet composition and fishing technology. Nevertheless, the model fits well to the CPUE data and the assessment is a valuable basis for giving short-term and long-term management advice.

Keywords: Bangladesh, Biomass model, Offshore shrimp stock, Stock assessment, Trawl logbook

Introduction

The fisheries sector of Bangladesh is important as a source of food, livelihood and foreign exchange earnings. The diverse fisheries resources are divided into three groups *viz.*, inland capture, inland culture and marine capture, with marine fisheries generating about 16% of the country's total fish production in 2015-16. Of this, marine shrimp accounts for 8% of total marine fisheries production and industrial shrimp trawl accounts for 6% of total marine shrimp production (DoF, 2017).

A number of pilot surveys were conducted in the beginning of the 1970s to assess the stocks of fish and shrimp in the Bay of Bengal. The surveys were initiated by FAO, at the same time as a demersal trawling fleet was developing and a number of stock assessments were carried out by international scientists in association with local experts. In the earliest assessment, West (1973) estimated a virgin stock of 6800-11400 t of shrimp biomass using the survey data collected during the period 1968-1971. Rashid (1983) calculated the standing stock of shrimp as 8400 t based on data from the Mitsui Tayo survey in 1976-77. A few years later, a survey was conducted using swept area method during 1981-83, which reported a standing stock of 3000-3600 t (White and Khan, 1985).

Industrial fishing through private ownership developed over the years (Rahman *et al.*, 1995) and by 2015-16 there were 204 industrial fishing vessels operating within the EEZ in waters of over 40 m depth, of which 31 were shrimping vessels (DoF, 2017). The shrimp catch is commercially categorised into 'tiger', 'white', 'brown' and 'flower'. The species caught are *Penaeus monodon* (Fabricius, 1798), *Penaeus semisulcatus* (De Hann, 1844), *Penaeus japonicus* (Spence Bate, 1888), *Penaeus indicus* (H. Milne Edwards, 1837), *Penaeus merguiensis* (De Man, 1888), *Metapenaeus monoceros* (Fabricius 1798), *Metapenaeus spinulatus* (Kubo 1949) and *Metapenaeus brevicornis* (H. Milne Edwards 1837) (Rao, 1987; Uddin *et al.*, 2012). Less commercially important species include *Parapenaeopsis sculptilis* (Heller, 1862), *Parapenaeopsis stylifera* (H. Milne Edwards, 1837) and *Acetes indicus* H. Milne Edwards, 1830. Brown shrimp is usually the highest in quantity forming around 60% of the annual shrimp catch (Uddin *et al.*, 2012).

Maximum sustainable yield (MSY) is usually used to establish a target harvest rate (Hilborn and Walters, 1992; Quinn and Deriso, 1999) in fisheries. When age or size composition data are not available, MSY reference points can be estimated using simple biomass models, such as the Schaefer (1954) and Fox (1970) models, where the effects of recruitment, growth and mortality are combined into a single production function. The two models are similar, but make slightly different biological assumptions about the shape of the surplus production as a function of biomass.

Standard biomass models like the Schaefer and Fox models have the following assumptions: (a) there are no species interactions, (b) the intrinsic growth rate is independent of age composition, (c) no environmental factors affect the population, (d) the intrinsic growth rate responds instantaneously to changes in population biomass with no time delays, (e) the catchability coefficient is constant, (f) there is a single stock unit, (g) fishing and natural mortality take place simultaneously, (h) no changes in gear or vessel efficiency have taken place and (i) catch and effort statistics are accurate (Musick and Bonfil, 2004). Although many of the assumptions are not very realistic, the model can be used to describe the main dynamics and historical trends for a given fishery and to form the analytical basis of advice for fisheries management.

Biomass models have been used in the past to evaluate MSY reference points for the Bangladesh shrimp fisheries. Khan and Hoque (2000) analysed the penaeid shrimp fishery data in Bangladesh marine waters and estimated the MSY as 4140 t using a Schaefer model and 4330 t using a Fox model. Kar and Chakraborty (2011) applied a Schaefer model together with a conventional economic model on Bangladesh shrimp fishery data and estimated the MSY as 3790 t. Ray and Khan (2003) applied related methods, the Verhulst equation and Pauly's model to data from Bangladesh shrimp fishery from 1981 to 1998 and estimated *r* as 1.33.

In this study, we attempted stock assessment of the offshore shrimp stocks of Bangladesh marine waters using latest analytical tools. The results are interpreted in the context of formulation of sustainable management measures in comparison with the findings of previous studies.

Materials and methods

Data sources

The time series data (catch and effort) of commercial shrimp stocks in Bangladesh marine waters from 1986 to 2016 (Fig. 1) were taken from logbook data sheets of the Marine Fisheries Office (Table 1). The prevalence of under-reporting of shrimp catch is considered to be low, since the majority of the catch of major shrimp species is exported. The catch data were converted from headless weight to total weight using the conversion factor of 0.63 for tiger shrimp, 0.66 for brown shrimp, 0.68 for white shrimp, and 0.65 for others. Shrimp trawlers engaged in fishing within the EEZ of Bangladesh beyond 40 m depth

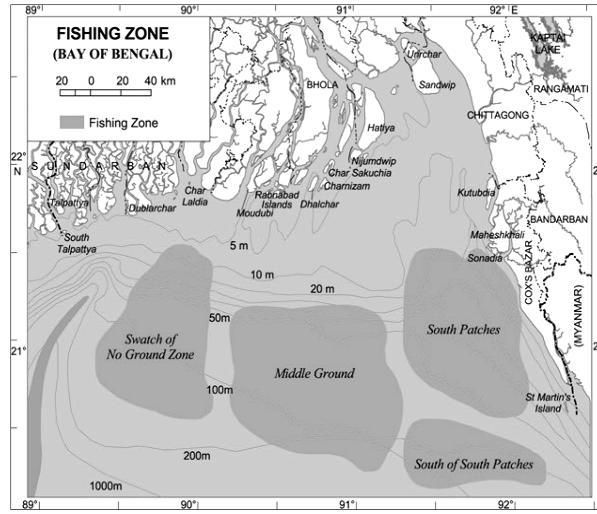

Fig. 1. Map showing the commercial fishing zone in Bangladesh marine waters

Table 1. Catch and effort data for the offshore shrimp fishery of industrial trawlers *(Source: Marine Fisheries Office report)*.

Year	Time (days)	Catch (t)	CPUE (t day^{-1})
1986	6429	6372	0.9911
1987	6642	5137	0.7734
1988	7806	7361	0.9430
1989	7394	4790	0.6478
1990	5658	5568	0.9841
1991	5529	4004	0.7242
1992	6588	5953	0.9036
1993	7113	5255	0.7388
1994	6691	3651	0.5457
1995	6502	5411	0.8322
1996	6914	5350	0.7738
1997	7044	3691	0.5240
1998	7645	5643	0.7381
1999	7152	4428	0.6191
2000	7289	4808	0.6596
2001	6935	4783	0.6897
2002	7069	3736	0.5285
2003	7442	4655	0.6255
2004	7866	4977	0.6327
2005	7466	5138	0.6882
2006	5919	3260	0.5508
2007	5969	3932	0.6587
2008	5956	4386	0.7364
2009	4581	3752	0.8190
2010	4718	4085	0.8658
2011	4116	3244	0.7881
2012	4436	4312	0.9720
2013	4935	5133	1.0401
2014	4543	3565	0.7847
2015	4703	3527	0.7499
2016	4635	4090	0.8824

contour usually have 150-250 t gross tonnage capacity with main engine power of 500-900 BHP. The maximum number of days of fishing per trip is 30 days. Trawlers typically complete 5-6 hauls per day, each for a period of 3-4 h. The fishing days and number of hauls vary depending on weather and sea worthiness of the vessel itself (Uddin *et al.*, 2012). The catch is expressed in metric tons (t) and effort is measured as the total number of fishing days of all vessels.

Biomass model

For this study, a Schaefer (1954) model was used to model the shrimp fishery,

$$B_{t+1} = B_t + rB_t\left[1- \frac{Bt}{K}\right] - C_t$$

where, B = biomass, t = time (year), K = carrying capacity, C = catch and r = intrinsic population growth rate. The biomass in the first year is modelled as $B_{init} = aK$, where the fraction a is an estimated model parameter, describing initial population size as a fraction of the carrying capacity. As indicated by the t subscripts, the population size can be evaluated one year further than the last year of catch data. Harvest rate is defined as the catch as a fraction of the biomass in a given year, $u_t = C_t / B_t$. The MSY-based reference points for the Schaefer model are:

$$u_{MSY} = 0.5\ r$$

$$B_{MSY} = 0.5\ K$$

$$MSY = 0.25\ rK$$

where B_{MSY} is the population size where the surplus production maximises, u_{MSY} is the optimal harvest rate, and MSY is the maximum sustainable yield (Polacheck *et al.*, 1993)

Model fitting procedure

The model is tuned to the biomass index time series, where the fitted indices are calculated as: $I_t = qB_t$ (Richards and Schnute, 1986), where I is the biomass index and q is the catchability coefficient, serving as a simple scaling factor. The biomass index can either be from the commercial fishery or based on survey abundance information (Barua *et al.*, 2018).

The model parameters were estimated by iteratively searching for parameter values that minimise the objective function, which is the negative log likelihood of the model fit,

$$-\log L = 0.5n \log (2\pi) + n \log \sigma + RSS / 2\sigma^2$$

where L = likelihood, n = number of biomass indices, σ = estimated variability of biomass indices, and RSS = residual sum of squared log residuals, $\Sigma(\log\hat{I}_t - \log I_t)^2$ Thus, a total of 5 model parameters were estimated: r, K, a, q and σ.

Statistical software

To ensure that the best parameter estimates were found, the parameter estimation was replicated in three different software platforms: Microsoft Excel Solver, AD Model Builder, ADMB (Fournier *et al.*, 2012) and Template Model Builder, TMB (Kristensen *et al.*, 2016). The latter two are based on automatic differentiation, which has been shown to be an effective technique when fitting nonlinear models (Bolker *et al.*, 2013). The ADMB-IDE environment (Magnusson, 2009) was used to develop and run the Schaefer model in AD Model Builder.

Evaluating uncertainty

The delta method (Seber, 1973) was used to construct confidence intervals around the estimated reference points. It is a built-in method in AD Model Builder and Template Model Builder, utilising exact partial derivatives, and is a recommended method to evaluate uncertainty about reference points in fisheries stock assessment (Magnusson *et al.*, 2013).

Results

Model fit and estimates

The model converged and resulted in similar parameter estimates in all three software platforms, Excel, ADMB and TMB and the confidence intervals from ADMB and TMB were similar between the two platforms. Overall, the model fits the biomass index quite well, capturing the main temporal trends in the observed data (Fig. 2).

Point estimates of parameters and key quantities are shown in Table 2, along with the 95% confidence intervals. The r and K parameters are estimated as 0.597 and 31544, respectively. The estimated harvest rate in 2016 is 20.4%,

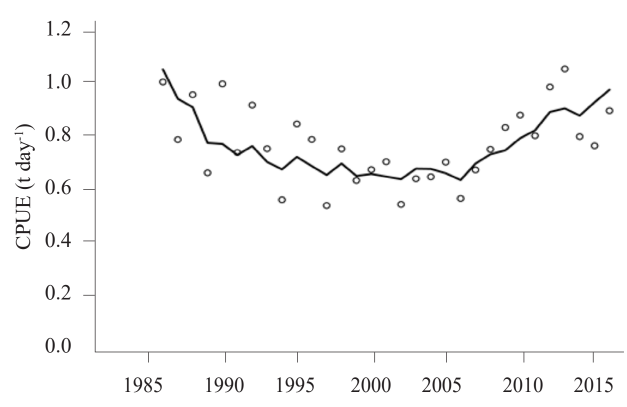

Fig. 2. Observed (circles) and fitted (line) biomass indices

Table 2. Point estimates and 95% confidence intervals of estimated parameters, biomass in 2017 and reference points.

Quantity	Estimate	95% CI
r	0.597	0.426 - 0.837
K	31544	22605 - 44018
a	0.685	0.511 - 0.918
q	4.81×10^{-5}	3.46×10^{-5} - 6.68×10^{-5}
σ	0.124	0.097 - 0.159
u_{2016}	0.204	0.159 - 0.263
B_{2017}	20286	15706 - 26201
uMSY	0.298	0.213 - 0.418
B_{MSY}	15772	11302 - 22009
MSY	4709	4565 - 4858

lower than u_{MSY} at 29.9%, while the estimated biomass in 2017 is 20286 t, higher than B_{MSY} at 15772 t. The average annual catch in 1986-2016 is 4645 t, close to the estimated MSY of 4709 t.

Estimates of historical stock size and harvest rate

The biomass is estimated as 2160 t in 1986, then gradually declining over the next two decades to 12910 t in 2006, increasing again in recent years to 20286 t in 2017 (Fig. 3). Catches were in the range from 3244 to 7361 t, with the highest catch in 1988 and the lowest in 2011. The harvest rate is estimated to have fluctuated between 18% and 40% in the years 1986-2016, with lower harvest rates (18% to 29%) in the last ten years (Fig. 4).

Discussion

Some of the key estimates resulting from the analysis of the population dynamics of the Bangladesh offshore shrimp fishery are : intrinsic growth rate (r) = 0.597 and carrying capacity (K) = 31544 t , corresponding to optimal harvest rate (u_{MSY}) = 30%, optimal stock size (B_{MSY}) = 15772 t and maximum sustainable yield (MSY) = 4709 t.

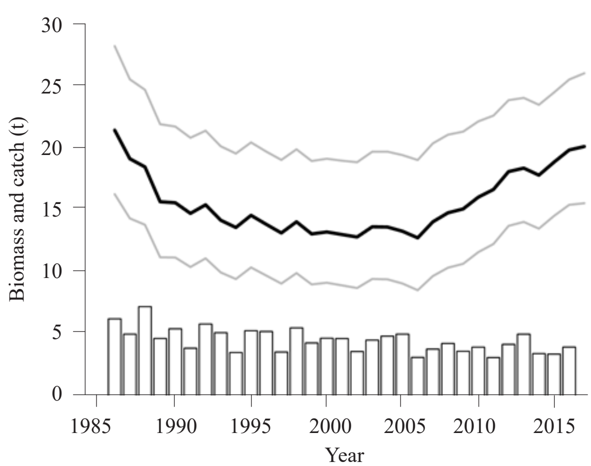

Fig. 3. Estimates of stock biomass (black line) with 95% confidence bands (gray lines), along with catch (bars)

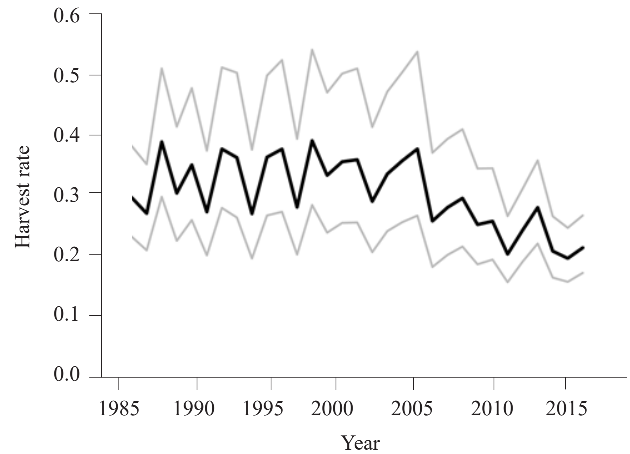

Fig. 4. Estimates of harvest rate with 95% confidence bands

Compared to earlier studies, the MSY estimate of 4709 t is higher than those reported by Khan and Hoque (2000), who estimated MSY as 4140 t or 4330 t, and also higher than the 3790 t estimated by Kar and Chakraborty (2011). The present analysis incorporates more data and the 95% confidence interval is 4565-4858 t, evaluated using the delta method. The estimated r of 0.597(0.426-0.837) in the current study is considerably lower than the 1.33 estimate from Ray and Khan (2003). The estimated value of r has a direct relationship with the estimated optimal harvest rate, in the context of a potential long-term target reference point for fisheries management. Finally, the estimated carrying capacity of K = 31544 t (22605 - 44018 t) is a bit higher than the early survey estimate of a virgin stock of 6800-11400 t by West (1973) and the 8400 t estimated from the 1976-1977 survey (Rashid,1983). The current estimates are likely to be more accurate than those from the earlier analyses, which tended to focus on equilibrium dynamics rather than the state of the fishery and looked at less complete datasets from the Bangladesh offshore shrimp fishery. The previous studies, however may indicate, in which direction the current estimates are likely to be biased.

If the biomass estimate in 2017 is multiplied by the estimated optimal harvest rate of 30%, the resulting catch advice could be interpreted as around 6060 t. This amount is higher than the most recent catch in the dataset, of around 4090 t in 2016. However, it should also be considered that there are other important sources of information about the status of the offshore shrimp fishery, beyond the catch and effort dataset used here such as, differences in catch rates between areas; changes in the geographical distribution of the stock and/or fleet; changes in the fleet composition;

and other aspects that are not easily included in a standard analytical biomass model.

Effort management policies have been used for this stock in the past. For example, in 2003, the authorities imposed restrictions on shrimp trawling, by not replacing old shrimp trawlers by new ones (MoFL, 2003). This resulted in decreased fishing pressure in the following years. Later, a policy of mandatory conversion of ground fish trawlers to mid-water trawlers to limit the fishing impacts on the sea floor and benthic habitat further decreased the fishing pressure on the shrimp.

Overall, there are indications that the stock is in a relatively good state, based on recent catch and effort trends in the observed data, as well as model estimates. The most recent harvest rates are estimated below the optimal, in contrast to the period from 1986 to 2008 when the average harvest rates were estimated to be higher than optimal. The results generated from the present study can be used for suggesting management measures, augmenting other sources of information of the offshore shrimp stock.

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